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DISTRIBUTION AND TRANSPORT OF SOME COMMON FORAMINIFERAL SPECIES IN THE MINAS BASIN, EASTERN CANADA

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ABSTRACT

The total population distributions of the more common foraminiferal species of the Minas Basin (an embayment of the Bay of Fundy in Eastern Canada) were surveyed and evaluated in relation to the tidally dominated environment of the study area. Results indicate that: (1) three foraminiferal associations occur in the Minas Basin apparently as a result of mixing of indigenous and allochthonous elements from adjacent environments through suspended load and/or bed load transport processes; (2) small fragile forms such as *Elphidium frigidum* may be carried in suspension above the bottom while other more robust species are judged to be transported as part of the bed load as evidenced by the abraded conditions of many of the tests of the robust types; (3) anomalously shallow occurrences of *Pyrgo williamsoni* and the occurrence of planktonic foraminifera in the basin suggests transport of tests into this area from the Bay of Fundy; and (4) the occurrences of *Ammonia beccarii* and *Elphidium margaritaceum* indicate relatively warm summer bottom water temperature in nearshore and intertidal environments compared to that normally associated with coastal environments on the Atlantic side of Nova Scotia.

INTRODUCTION

The aim of this paper is to describe the occurrence and distribution patterns of several relatively ubiquitous indigenous species of foraminifera observed in the Minas Basin and to relate aspects of the transport features observed on their external test surfaces that were first reported in an earlier unpublished work (Thomas, 1977) to what is presently known of the hydrologic conditions of the study area. Determination of the absolute degree of species redistribution throughout the basin is limited in that living specimens were not identified in the samples so that allochthonous and autochthonous components could not be readily distinguished by this method.

The Minas Basin is an embayment situated at the head of the Bay of Fundy in Eastern Canada (Fig. 1). The basin is a unique environment for several reasons, the single most important of which is its exceptionally large tidal range (16.3 m, Dawson, 1917). The tides produce currents in excess of 2.0 m/s in the surface water layer and over 1.0 m/s near the bottom (Amos and Joice, 1977). These velocities are well in excess of that required to erode and transport foraminifera (Sternberg and Marsden, 1979).

The species discussed in this paper may have potential use as indicators of the transport direction of bottom sediments and may ultimately be helpful in determining the influence of tidal power barriers on the modal sediment transport pattern in the basin. The baseline data might also be useful in showing future

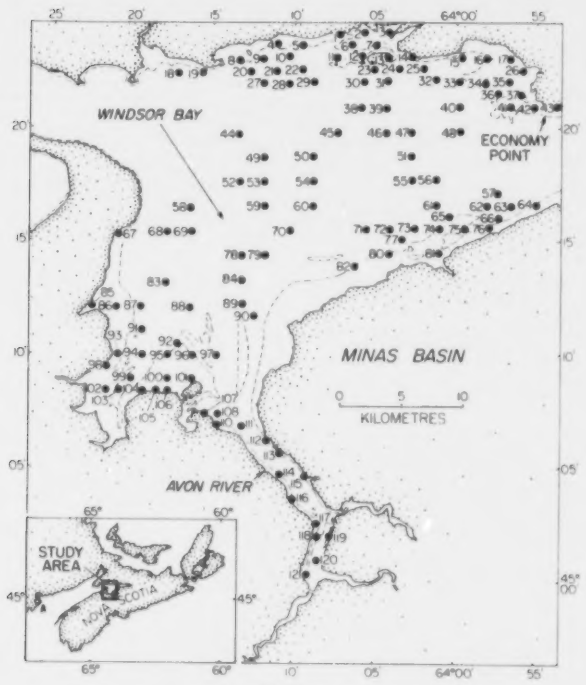

FIGURE 1
Map showing locations of samples used in this study. Inset shows location of study area.

changes in the benthic environment that could result from anthropogenic modification of natural tidal flushing and mixing processes.

METHODS

The results presented in this paper are based on 120 sediment samples collected during the spring and autumn months of 1976 (see Fig. 1). In late May of that year bottom samples were collected in offshore areas from CSS *Dawson* using a medium (30 cm × 30 cm) Van Veen grab (Amos and others, 1976). The nearshore sites were sampled in September and October from a small boat using an 18 cm × 18 cm Ekman grab, or on foot with a spade during low tide (Long, personal communication). Initial examination of the samples showed no evidence of gypsum crystals (Schnitker and others, in press) and therefore no post-collection solution of specimens is assumed.

ENVIRONMENTAL SETTING

Bottom sediments in the basin range from muddy sands and sands in the extensive tidal flats to sandy gravel and gravel in the deeper offshore areas (Amos and Long, 1980; Fig. 10). The detailed sediment dynamics of the basin are quite complex and are discussed elsewhere (Amos and Long, 1980). In general, suspended material is brought into the basin from the Bay of Fundy and from eroding cliffs surrounding the basin. Most of the material coming from the bay source is biogenic debris of silt and/or clay size, while that originating in the basin is derived from glacial till. The eroding cliffs surrounding the basin supply large amounts of sand-size lithogenic material to the system. During periods of intense wave-generated turbulence, much of this material is resuspended and, under the influence of the comparatively strong tidal currents, a substantial amount is redistributed during each cycle (Amos and Long, 1980). Studies of the suspended particulate matter loads (SPM) in the basin using both conventional water sampling procedures (Amos and Joice, 1977) and satellite imagery (Amos and Alföldi, 1979) indicate that suspended sediments may reach concentrations up to 2,700 mg/L near the entrance to Cobequid Bay in the western part of the basin and also along the south side of the Avon River estuary near the mouth of the river.

Bottom water salinities in the basin are generally uniform from season to season. In the lower reaches of the basin the range is 31.0–32.9‰, while at the head of the basin values are slightly lower (30.0–32.7‰). Salinity increases on the average by about 1.1‰ throughout the basin at high tide (Amos and Long, 1980).

Bottom water temperatures vary from less than 0°C in winter to 21°C in late summer (Amos and Joice, 1977; Amos and Long, 1980). Significantly, summer values may vary as much as 5°C during a tidal cycle because of heat transferred from the sun-warmed tidal flat sediments to the incoming tidal water. Although tidal turbulence results in intensive vertical mixing, temperature stratification of the water column has been observed in the summer months over periods of several hours (Amos and Long, 1980). Because of the confined morphology of the basin, stratification of the water column can be enhanced by above average freshwater discharges that may occur as a result of comparatively wet spring and summer seasons. Bishop and others (1980) observed a somewhat analogous effect near Point Lepreau in the Bay of Fundy and related it to a high freshwater discharge from the St. John River during the spring of 1979.

An outstanding characteristic of the basin is the high population density of the macrobenthic assemblage that inhabits parts of the extensive tidal flat areas. Risk

and others (1977) report population densities of up to 560 individuals/m² of *Mya arenaria*, the common soft-shelled clam. They observed that the total species diversity of the macrobenthos appears to be relatively low, with less than 90 species represented in the tidal flat environment.

Chlorophyll "a" content of water samples from the basin is generally less than 0.5% by weight (Amos and Alföldi, 1979). Risk and others (1977) described the chlorophyll "a" content in the basin water as being near the lower limit of detectability and also reported very low fat reserves in zooplankton. These observations were interpreted as being indicative of a paucity of food material for these organisms in the study area. They speculated further that bacteria may play an important role in the food chain of the study area by breaking down relatively refractory material such as cellulose and chitin into high protein bacterial biomass that can then be eaten by deposit feeders. Much of this activity presumably occurs at the sediment-water interface and thus provides a food source for other benthic organisms, including foraminifera. Risk and others (1977) also suggested that the high macroinvertebrate population densities found in the basin might be supported, in part, by in situ production of benthic algae on the mudflats.

PREVIOUS WORK

In an earlier unpublished study of total foraminiferal populations, Thomas (1977) indicated that the 40 foraminiferal species encountered could be grouped intuitively into three associations based on a comparison of their generalized distribution patterns with those reported in the literature for comparable environments (Bartlett, 1964, 1965; Boltovskoy and Wright, 1976; Murray, 1971; Scott and others, 1977; Todd and Low, 1961). One of these assemblages was restricted to some of the nearshore or intertidal environments and was only occasionally observed at some of the deeper water locations. This association included *Miliammina fusca* and several species of the genera *Lagena*, *Bolivina* and *Oolina*. All of these species have relatively small, fragile tests and, except for *Miliammina fusca*, most exhibited some degree of abrasion damage on their test surface.

A second association consisted of forms that occurred in several geographically restricted environments in the basin. Certain species were fairly common in the Avon River estuary, but also occur occasionally in the central portion of the basin and at a few nearshore localities around the perimeter of the study area. *Trochammina inflata*, *T. lobata*, *T. ochracea*, some species of the genus *Islandiella*, *Trifarina angulosa*, *Rosalina columbiensis*, *Buccella frigida*, *Elphidium margaritaceum* and several planktonic forms comprised this association. Most taxa in this association possessed rather robust and unabraded tests, although *Rosalina columbiensis*, *Buccella frigida* and the planktonic forms are comparatively small and fragile. Transport of the species in this association was presumed to have been in suspension, thereby avoiding the test abrasion that could result from bottom transport as suggested in the situation described by Loose (1970).

The occurrence of unabraded planktonic specimens in the Avon River estuary supports the hypothesis of suspension transport for this association. The mean maximum diameter of the planktonic tests in all samples is 0.23 mm, a size which is easily eroded. Because the tests have a lower density than the quartz spheres used in published models (Hjulström, 1939), they could be carried in suspension for extended periods by the turbulent high velocity tidal currents that are known to prevail in the basin. Murray (1965) reported similarly that wave base disturbances in the English Channel and Celtic Sea had thrown foraminiferal tests into suspension, and that wave turbulence had caused those in the size range of 0.15 to 0.20 mm to rise to the surface layer of the sea. This would be expected in the case of foraminifera tests because of their lower "envelope" density, which on the average is equal to or less than 2.0 g cm^{-3}.

A third association observed in the basin consisted of ubiquitous species, almost all of which have relatively large and/or thick-walled tests. This association included *Quinqueloculina seminulum*, *Pyrgo williamsoni*, *Ammonia beccarii*, *Eggerella advena*, *Elphidium excavatum* group, *E. frigidum*, *E. subarcticum* and *Cibicides lobatulus*. The morphological anomalies within this association are *Elphidium frigidum* and *Eggerella advena*, both of which are relatively small forms. The population of these two species found in the Minas Basin had an average diameter of approximately 0.28 mm and a maximum length of 0.21 mm. Thomas (1977) speculated that the apparent widespread distribution of the ubiquitous species association may have been controlled largely by the durability of their tests. Species with large, robust tests were inferred to withstand more frequent and longer periods of transport and more frequent recycling, thereby achieving a wider distribution than those forms having small and fragile tests. The larger tests were presumed, in addition, to have been restricted to the bed

TABLE 1

Abundance and distribution statistics for major species. Frequency (F) is the number of occurrences of a species in the samples expressed as percent, $\bar{x}$ is the mean number of specimens per gram of dry sediment, s is the standard deviation of $\bar{x}$, V is the coefficient of variation, and FN/cc is an estimate of the total Foraminiferal Number, i.e., the number of specimens per cc of wet sediment (based on an assumed density of 0.7 g/cc dry sediment).

Species	F	$\bar{x}$	s	V	FN/cc
Elphidium excavatum group	88	5.85	24.37	101.5	4.1
Cibicides lobatulus	79	1.68	7.23	31.3	1.2
Ammonia beccarii	70	0.33	0.64	1.2	0.2
Elphidium frigidum	62	9.52	57.53	347.6	6.7
Quinqueloculina seminulum	60	0.12	0.24	0.5	0.1
Eggerella advena	54	1.59	7.84	38.6	1.1
Pyrgo williamsoni	39	0.11	12.80	1,489.4	0.1
Elphidium margaritaceum	31	0.34	1.29	4.9	0.2
Miliammina fusca	19	0.21	0.43	204.7	0.1

TABLE 2

Average sizes of the eight most ubiquitous benthonic species and of the planktonic foraminifera in the Minas Basin compared to sizes noted in the literature for these species.

Species	Minas Basin	Size (in mm) British Isles (Murray, 1971)	Arctic (Loeblich and Tappan, 1953)
Ammonia beccarii	0.58	0.40	
Cibicides lobatulus	0.43	0.80	
Eggerella advena	0.28		0.68–0.39
Elphidium excavatum group	0.40	0.30	0.60–0.53
Elphidium frigidum	0.21		0.94–0.44
Elphidium margaritaceum	0.34		
Pyrgo williamsoni	0.58	0.40	0.85–0.57
Quinqueloculina seminulum	0.53		
Planktonic foraminifera	0.23	0.20*	

* Size given for *Globigerina pachyderma*, the most common of the few planktonic forms occurring in the Basin.

load regime for comparatively larger intervals of their total transport history.

RESULTS AND DISCUSSION

The distribution patterns of the nine most ubiquitous species observed in the basin are documented in this report (Tables 1 and 3, Figs. 3–11). They include the most abundant species observed which, because of their prominent position in the total population, have the best potential for use as indicators in interpreting past and future environmental variations.

In terms of sheer physical size, these nine species can be grouped into three categories:

1. Relatively large, heavy species including *Ammonia beccarii*, *Pyrgo williamsoni*, and *Quinqueloculina seminulum*.
2. Species of average or intermediate size, including *Cibicides lobatulus*, *Elphidium excavatum* group, *Elphidium margaritaceum* and *Miliammina fusca*.
3. Small species, including *Eggerella advena* and *Elphidium frigidum*.

The spatial distribution relationships among these species were tested initially using cluster analysis (Bonham-Carter, 1967). In this instance the percentages of each species at each station were compared with each other (R-mode) using the Dice coefficient (D) where $D = 2C/(N_1 + N_2)$. C is the number of samples in which the species are both present and N_1 and N_2 are the total number of samples in which the respective species being compared occur. This coefficient tends to emphasize the co-occurrence of species. The resulting matrix of coefficients was clustered using the unweighted pair-group method (Sokal and Michener, 1958). The dendrogram plot of the calculated species associations (Fig. 2) emphasizes the relatively strong similarity between the *Elphidium excavatum* group and *Cibicides lobatulus* distribution patterns, and the distinctive character of the other size-dependent species distribution relationships described earlier.

A detailed discussion of distributional characteristics of these three groups in the Minas Basin is given below. Author citations for all species except *Elphidium excavatum* group are as noted by Cole and Ferguson (1975), Scott and Medioli (1980), and Scott and others (1980). *Elphidium excavatum* group is an informal designation given by the authors to include several closely related forms resembling *Elphidium excavatum* (Terquem).

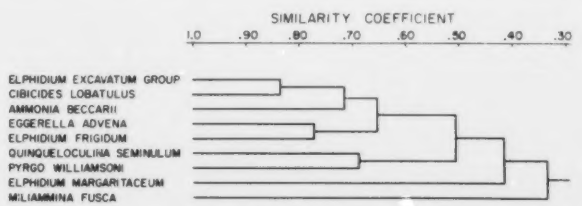

FIGURE 2

Dendrogram plot of common foraminiferal species using Dice coefficient of association and weighted pair group method to show similarity of species distributions.

TABLE 3 (a, b and c)

Sample data. Sample numbers correspond to the station numbers shown in Fig. 1. Water depths are given in meters for each station (I denotes intertidal zone). Numbers given for the species in each sample are percentages of the total foraminiferal assemblage found at that station.

SAMPLE NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
WATER DEPTH	I	I	I	I	1	I	I	1	2	3	I	I	1	I	2	2	I	3	3	4	4	4	3	4	5	I	10	11	12	6	7	4	2	1	I	1	I	11	12	3
NO. SPECIES PRESENT IN SAMPLE	3	10	8	12	14	7	10	8	7	10	9	13	6	6	14	8	16	9	11	12	14	12	9	10	8	19	7	9	9	14	11	11	10	6	2	4	6	12	12	11
TOTAL NUMBER OF SPECIMENS COUNTED IN SAMPLE	40	2072	61	54	1392	54	83	49	60	101	35	976	61	15	171	71	3362	185	356	1824	1960	256	1360	50	37	4096	127	125	261	339	323	99	98	25	2424	9	92	2912	180	211
SPECIES NAME	COUNT EXPRESSED AS PERCENT OF TOTAL SPECIMENS																																							
AMMONIA BECCARII	23		5	3	2			55	18	12		2	20	27	9	12		6	7	2	2	10	1	22	9		78	2	23	16	12	8	7	44		22	8	2	8	6
ASTACOLUS HYALACRULUS																									3																
BOLIVINA PSEUDOPLICATA		1		1																						1				1										
B. PSEUDOPUNCTATA																														1										
BUCELLA FRIGIDA				5				2						13						1	6					1		4			3		2						
CIBICIDES LOBATULUS		1		10	13	22	8		17	13	23	8	16	13	5	21	6	14	8	2	5	6	6	10	8	12	6	17	15	8	8	15	8	8				10	7	9
EGGERELLA ADVENA		8		3	6		14			10		7			7		10	9	6	2	5	16				8	1	11		6	3	18	11					4	10	7
ELPHIDIUM EXCAVATUM GROUP	23	5	18	55	14	28	6	21		24		22	44	20	16	13	22	21	16	28	4		27	14	32	12	5	10	8			12	16	20	98	11	28	6	26	24
E. CRISPUM											3											1								1										
E. FRIGIDUM		78	16	2	17		7		20	27	11	22			9	10	14	18	33	29	43	24	32	20		25		2	6	12	52	8	21	8			25	34	10	20
E. MARGARITACEUM		2			12		12				6	2			10	3	12		3	1		3	1	4	8	4					2								6
E. SUBARCTICUM		4	33		17	22	29	8	22	5	26	25	15	20	19	19	16	18	21	31	26	14	29	6	13	25	6	46	40	33	14	15	17			25	30	28	17
EPONIDES UMBONATUS																	2													9										
FISSURINA MARGINATA																														1										
GLABRATELLA WRIGHTII					5							2			5																									
GLOBIGERINA PACHYDERMA																	2	1								2														
HASTIGERINA AEQUILATERALIS																																								
ISLANDIELLA ISLANDICA		1				7																12				1							4							
ISLANDIELLA TERETIS								2																								2	1							
?ISLANDIELLA? SP										2					1																									
LAGENA MERIDIONALIS					1				2																															
L. MOLLIS																	1									1														
L. SEMILINEATA																																								
MILLIAMMINA FUSCA					1		10			2	9					14								4		1					1		4					1		2
OOLINA COSTATA																																								
O. LINEATA																				1	1																			
O. MELO																																								
O. SP.																																								
PSEUDOPOLYMORPHINA NOVANGLIAE																													1											
PYRGO WILLIAMSONI						8		2			3	2		7	1		1		1	1	1	4	2	4	16	1		2	4	4	3	3	5					1	2	2
QUINQUELOCULINA SEMINULUM	54		3	2	1	11				2	14				2	8	2	4	3	1	1	6	1	6	11	1	2		2	2	3	9	10	18		58	10	3	9	3
ROSALINA COLUMBIENSIS				11	6		6		8			2									2		1			1				5	3						3		
SACCAMINA ATLANTICA																			1																					
SPIROPLECTAMMINA BIFORMIS				2													1									1				1										
TRIFARINA ANGULOSA													3		2		1																		11					
TROCHAMMINA INFLATA			8	2		2					5	2			4					1	1	2				1			1											
T. LOBATA		1	7		1		4	8		3		1	2				2		1		1	2				1					1					4	1		
T. MACRESCENS																	1																							
T. OCHRACEA		1	10	4	4		4	2	13			3			10		2	9			2			10		1	2	6				7					5		4

Large Species

Ammonia beccarii (Linné) is one of the largest species found in the study area (Table 2) and is distinguished by its thick-walled test which is often heavily abraded (Pl. 1, Figs. 3 and 4). Commonly the ultimate and/or penultimate chamber is missing from the test. This species was included among the transport-susceptible types in St. Georges Bay, Nova Scotia (Schafer, 1976). In the basin, its overall abundance distribution is comparatively regular but its frequency is often higher in nearshore environments (Fig. 3). The extensive test damage often seen on *A. beccarii* specimens may indicate periods of transport as part of the bed load (Boltovskoy and Wright, 1976), a process which could easily result in development of the damaged tests observed in the earlier study (Thomas, 1977).

Quinqueloculina seminulum (Linné), another large species indigenous to the Minas Basin, exhibits a distribution similar to that of *A. beccarii* (Fig. 5) and often displays a similar degree of test abrasion (Thomas, 1977). *Pyrgo williamsoni* (Silvestri) is also found predominantly in nearshore sediments (Fig. 4), although less frequently than either *A. beccarii* or *Q.*

SAMPLE NUMBER	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
WATER DEPTH	1	1	1	25	19	21	20	21	20	17	16	17	16	15	13	14	13	21	17	13	8	5	3	1	1	1	1	17	15	12	6	5	2	1	1	1	1	10	9	1
NO. SPECIES PRESENT IN SAMPLE	3	5	4	8	7	2	8	10	4	8	2	12	11	9	4	1	3	5	11	3	8	7	10	5	7	11	2	8	11	8	7	13	11	5	10	13	10	5	6	6
TOTAL NUMBER OF SPECIMENS COUNTED IN SAMPLE	6	39	7	39	32	3	161	45	17	117	3	166	330	45	4	1	10	32	140	6	35	47	70	19	12	385	21	46	89	64	452	4704	1952	48	88	1840	93	59	112	1320
SPECIES NAME	COUNT EXPRESSED AS PERCENT OF TOTAL SPECIMENS																																							
AMMONIA BECCARII	17					33	6	13	12	15	33	6	3	20	25			32	9		14	11	7	16	8	5			3	28	11	7	3	17	10	2	22	59	57	1
ASTACOLUS HYALACRULUS																																								
BOLIVINA PSEUDOPLICATA																										4						1								
B. PSEUDOPUNCTATA				3	3							1							4												1			2					
BUCELLA FRIGIDA												1																	1	3		1			4					
CIBICIDES LOBATULUS	33	18		5			8	9	47	21		22		13	25			48			17	19	10	21	34	5		17	22	16	18	1	10	19	12	3	17	14	7	43
EGGERELLA ADVENA				8	3		8	3		4		3	8				50		8				9			5		12	2			39	3			2				
ELPHIDIUM EXCAVATUM GROUP	50	38	29	15	18		27	18		15		14	22	18			30	10	7	83	24	31	21	42	17	19	5	42	61	9	59	40	20	46	32	30	16	15	15	50
E. CRISPUM																																								
E. FRIGIDUM			29	48	47		23	24			87		25	2	25				21		14	23	19			32	95			2		5	26		22	27	32			
E. MARGARITACEUM		10															20				5	2	11								5	2							
E. SUBARCTICUM			29				26	18	29	25		36	28	34				7	29		11	12	16	11	17	15				33			30		15	29	5	8		4
EPONIDES UMBONATUS								2																											1					
FISSURINA MARGINATA																																								
GLABRATELLA WRIGHTII								3																																
GLOBIGERINA PACHYDERMA												1							2						8				1						1					
HASTIGERINA AEQUILATERALIS								3																																
ISLANDIELLA ISLANDICA																						2										1								
ISLANDIELLA TERETIS													2										3									1		4						
?ISLANDIELLA? SP.														2											8				1						1					
LAGENA MERIDIONALIS																																								
L. MOLLIS																																								
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MILLIAMMINA FUSCA										9											9					4														
OOLINA COSTATA																																								
O. LINEATA																																								
O. MELO																																								
O. SP.												1																												
PSEUDOPOLYMORPHINA NOVANGLIAE																																							7	
PYRGO WILLIAMSONI		13			3								3										3								3	1	2		1	1	2	7	1
QUINQUELOCULINA SEMINULUM		21			9	67	3	7	12			11	2	2	25	100			3		6			10	8			4	1	8	2	1		14		1		4	7	
ROSALINA COLUMBIENSIS										4			4					3	11	25									1							1			
SACCAMINA ATLANTICA																																								
SPIROPLECTAMMINA BIFORMIS								1				1							1																					
TRIFARINA ANGULOSA			13																				1			3		4	1				1			1	2			1
TROCHAMMINA INFLATA																										4									1	1	2			
T. LOBATA													1	2															1		2	1	1		1					
T. MACRESCENS																																								
T. OCHRACEA				21	19					7		3	4	7					5	12						4		21	6							1				

seminulum, and is often seen in a somewhat abraded state in the study area (Pl. 1, Fig. 5).

Pyrgo williamsoni is reported from coarse nearshore sediments in Chaleur Bay, New Brunswick (Schafer and Cole, 1978), but is regarded generally as a deep bay form that is usually associated with muddy substrates and comparatively high salinities (e.g., >29‰). Its presence and distribution pattern in the basin are somewhat anomalous, since the three localities where its concentration is highest are all very shallow water estuarine environments. The presence of this species in the basin could be considered to indicate tidal current bed load transportation of relatively coarse sediments into the Minas Basin from the seaward Bay of Fundy, a situation opposite to one reported for the Bristol Channel, U.K. by Culver (1980, see below).

Average or Intermediate Size Species

Cibicides lobatulus (Walker and Jacob) is very common in the Minas Basin, appearing in more than 70% of the samples, and often in comparatively high abundances (Fig. 6). Many specimens of *C. lobatulus* collected from the study area show extensive test abra-

SAMPLE NUMBER	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	110	111	112	113	114	115	116	117	118	119	120	121
WATER DEPTH	1	1	8	5	1	1	2	2	3	4	1	2	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
NO. SPECIES PRESENT IN SAMPLE	8	15	8	3	2	10	16	13	12	8	6	10	5	10	14	6	15	8	8	16	10	8	5	8	5	1	1	7	3	9	14	13	9	13	7	4	16	7	5	1
TOTAL NUMBER OF SPECIMENS COUNTED IN SAMPLE	133	546	232	3	6	37	489	746	106	55	9088	68	54	408	412	103	299	166	85	10940	105	11088	382	36	269	6	1	1480	12	277	1119	15682	3425	1054	2752	23	33600	94	656	1
SPECIES NAME	COUNT EXPRESSED AS PERCENT OF TOTAL SPECIMENS																																							
AMMONIA BECCARII	40	3	22			3	21	15	5	16		6		9	3	8	7		13										16	3	1	1	2	3						
ASTACOLUS HYALACRULUS																																								
BOLIVINA PSEUDOPLICATA									2											1														1						
B. PSEUDOPUNCTATA																									12															
BUCELLA FRIGIDA		2						1			1					2	1													12	2		3			1			
CIBICIDES LOBATULUS	29	25	28	33			14	24	10	9		19	2	17	17	10	34	9	20		15	1	13	8				17			24	21	8	11	2	22	6	14		
EGGERELLA ADVENA		5	9			10	9	3	5			10		3	8		1		12	2	4	5	4	22	11			13		22	1		28	6	6		10	12	36	
ELPHIDIUM EXCAVATUM GROUP	15	51	33	33		42	20	39	21	58	4	41	57	29	34	78	41	5	26	29	55	1	44	11	9			15	42	30	61	32	27	34	28		25	57	15	100
E. CRISPUM																				1																				
E. FRIGIDUM		1				9	8	3	18		71	7		20						30		35		28	56		100	36	42	8		5	12	15	12		17		12	
E. MARGARITACEUM					83		5	1		2		6						57		1		1		14							3				65	1	5		
E. SUBARCTICUM	7		5	33		14	10		24	9	17		15	18	23		2	13	9	28	11	37	35	17		100		17		19		30	10	15	39	4	18		22	
EPONIDES UMBONATUS																																								
FISSURINA MARGINATA												2		1						1																				
GLABRATELLA WRIGHTII															1																									
GLOBIGERINA PACHYDERMA						3	1								1		1				2							1			1									
HASTIGERINA AEQUILATERALIS																																								
ISLANDIELLA ISLANDICA		1										3					1			1	2										1								
ISLANDIELLA TERETIS						3	1		2						2		1												2								1	4		
?ISLANDIELLA? SP		1																													1									
LAGENA MERIDIONALIS																																								
L. MOLLIS																						1									1			1			1			
L. SEMILINEATA																															1									
MILLIAMMINA FUSCA		1					2										1	3														1							
OOLINA COSTATA																															1						1			
O. LINEATA																																								
O. MELO		1																																						
O. SP																																								
PSEUDOPOLYMORPHINA NOVANGLIAE		1	1				1	1							1					1																				
PYRGO WILLIAMSONI	1	1	1				1	1							1		1			1											1	1					1			
QUINQUELOCULINA SEMINULUM	5	1	1			3		4	6	7		5	24	1	1		1		8	1											1	1					1			
ROSALINA COLUMBIENSIS									5						2			2																						
SACCAMINA ATLANTICA													2	1																										
SPIROPLECTAMMINA BIFORMIS							1									1				1														1						
TRIFARINA ANGULOSA	1	5					2	4							2	3	4		5	1	2		4							2	2	2		3			6	4		
TROCHAMMINA INFLATA	2					8	2	2	2			3		1	4		3	6	7	1	3									2	2	1	2	3	6		1			
T. LOBATA		1			17	5	2	1									1	5		1														1	8		1	4		
T. MACRESCENS																					2																			
T. OCHRACEA								1		1	7										4	19			12			1				1	8	8		9	9		15	

sion (Pl. 1, Fig. 1). Some have their entire dorsal surfaces removed, revealing the interior of many of the chambers. Abrasion effects of this intensity indicate widespread transportation of at least some of these tests, or abrasion by other particles while the test is still attached to the substrate. The abundance distribution pattern of this form suggests a preference for high energy environments, a possibility that is supported by Bartlett's (1964) observation of this species as a common constituent of foraminiferal lag deposits in St. Margaret's and Mahone Bays, Nova Scotia. Loose (1970) also found living specimens of *C. lobatulus* in plankton tows off Bodega Head, California. In the Minas Basin, tests of this species could become separated from the substrate before or after the death of the organism, and then be transported as bed load or in suspension to various parts of the basin.

The *Elphidium excavatum* group is the most ubiquitous taxon in the basin (Fig. 7). Its average size in the study area is comparable to that of *C. lobatulus* (see Table 2) and it often exhibits a similar degree of abrasional damage (Pl. 1, Figs. 2 and 6). Schafer (1976) noted that *E. excavatum* group was among the most transport-susceptible members of the shallow water assemblage observed in St. Georges Bay, Nova Scotia. The relatively high mobility of living specimens of this form (Schafer and Young, 1977) could be related to its adaptation to the shifting sediment substrates

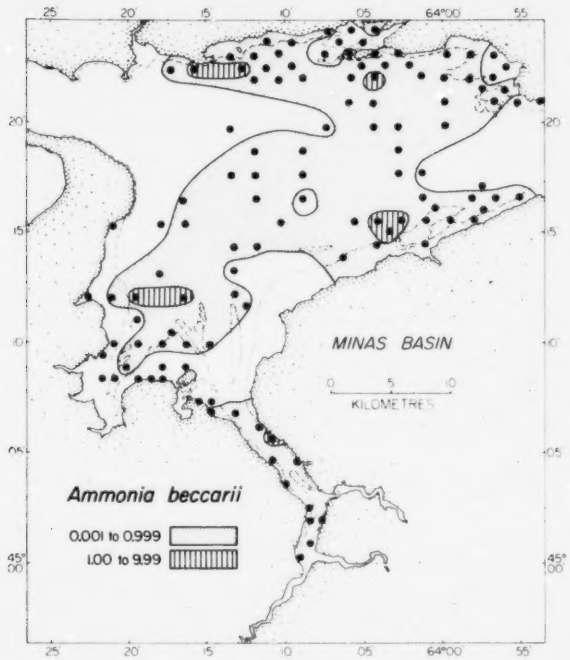


FIGURE 3

Distribution of specimens per gram of dry sediment of *Ammonia beccarii*.

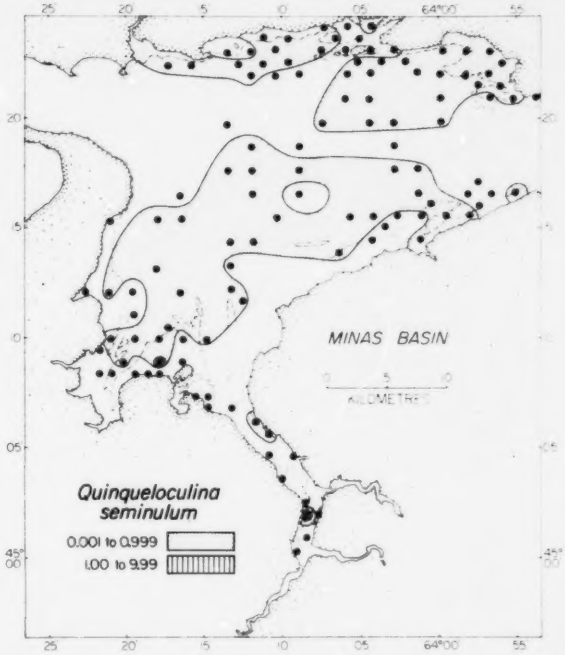


FIGURE 5

Distribution of specimens per gram of dry sediment of *Quinqueloculina seminulum*.

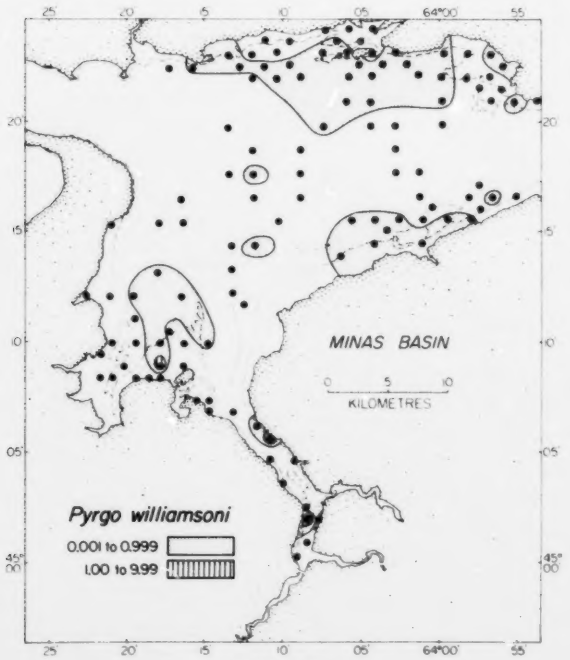


FIGURE 4

Distribution of specimens per gram of dry sediment of *Pyrgo williamsoni*.

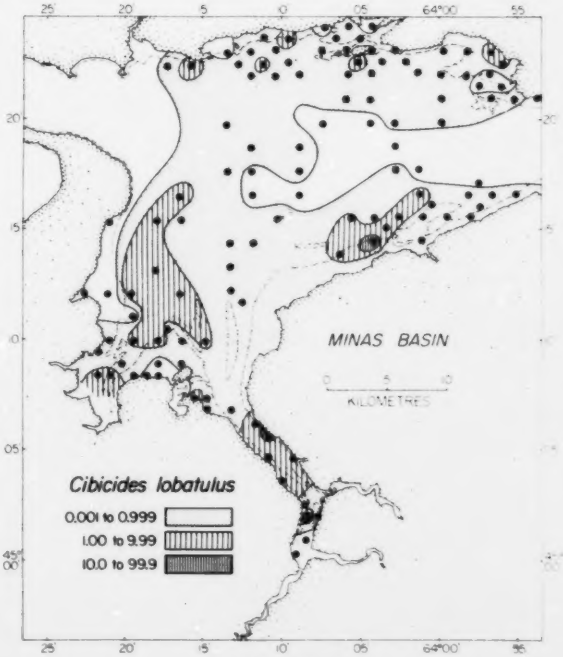


FIGURE 6

Distribution of specimens per gram of dry sediment of *Cibicides lobatulus*.

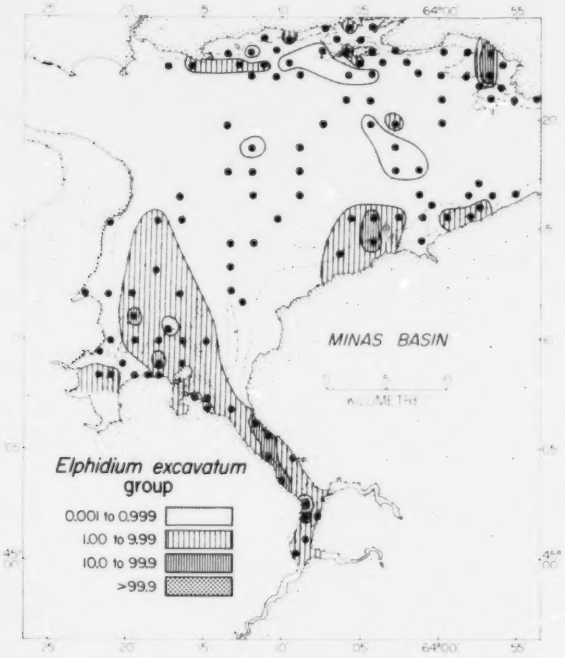


FIGURE 7

Distribution of specimens per gram of dry sediment of *Elphidium excavatum* group.

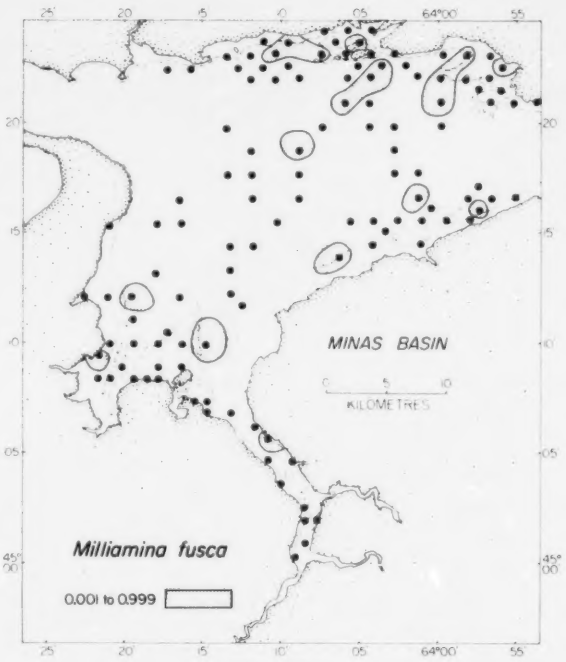


FIGURE 9

Distribution of specimens per gram of dry sediment of *Milliamina fusca*.

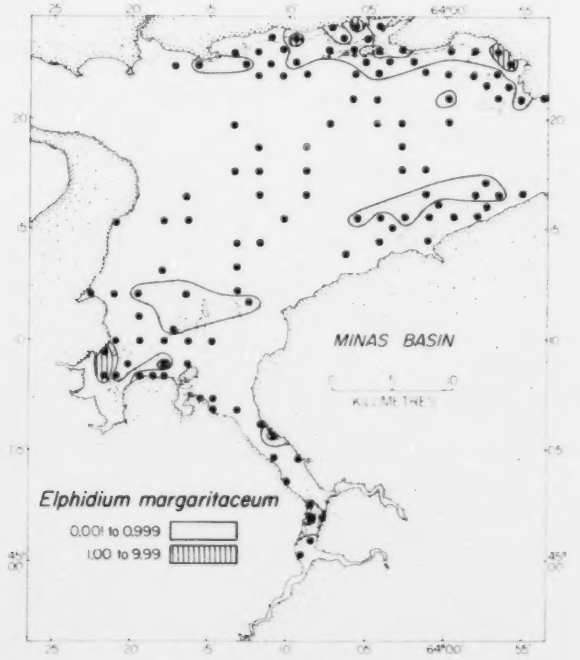


FIGURE 8

Distribution of specimens per gram of dry sediment of *Elphidium margaritaceum*.

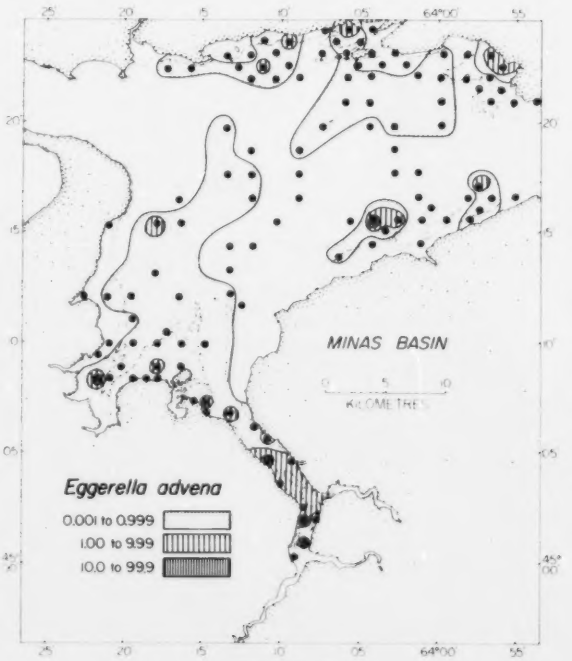


FIGURE 10

Distribution of specimens per gram of dry sediment of *Eggerella advena*.

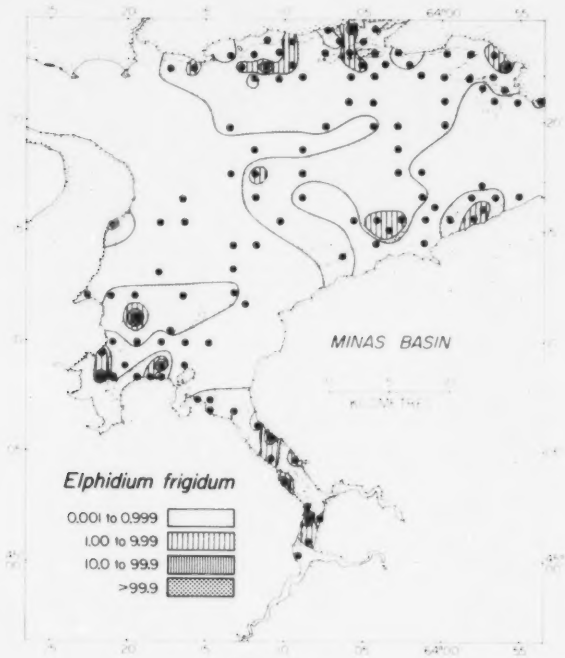


FIGURE 11

Distribution of specimens per gram of dry sediment of *Elphidium frigidum*.

that typify many nearshore Maritime benthic environments. The equivalent diameter of the group (i.e., the diameter of a quartz grain having the same settling velocity) falls within the range of 0.10 to 0.16 mm for specimens with an average diameter of 0.35 mm (Haake, 1962; Grabert, 1971). Since the modal diameter of this group in the basin is only slightly larger (i.e., 0.40 mm) most forms would therefore be included in the size range of the most easily eroded particles (Shepard, 1963, p. 128).

Elphidium margaritaceum (Cushman) is also similar in size to *C. lobatulus* (Table 2) but is much less common in the basin (Fig. 8), being confined primarily to nearshore localities. Similarly, *Miliammina fusca* (Brady) also fits into this category, and its distribution in the basin (Fig. 9) resembles that of *E. margaritaceum*.

Neither *E. margaritaceum* nor *M. fusca* commonly exhibit pronounced abrasional effects in the study area. It is possible that since both species are found largely in the very nearshore and/or intertidal areas of the basin, they are not subjected to the relatively strong and prolonged tidal currents that characterize the deeper portions of the basin (Amos and Joice, 1977).

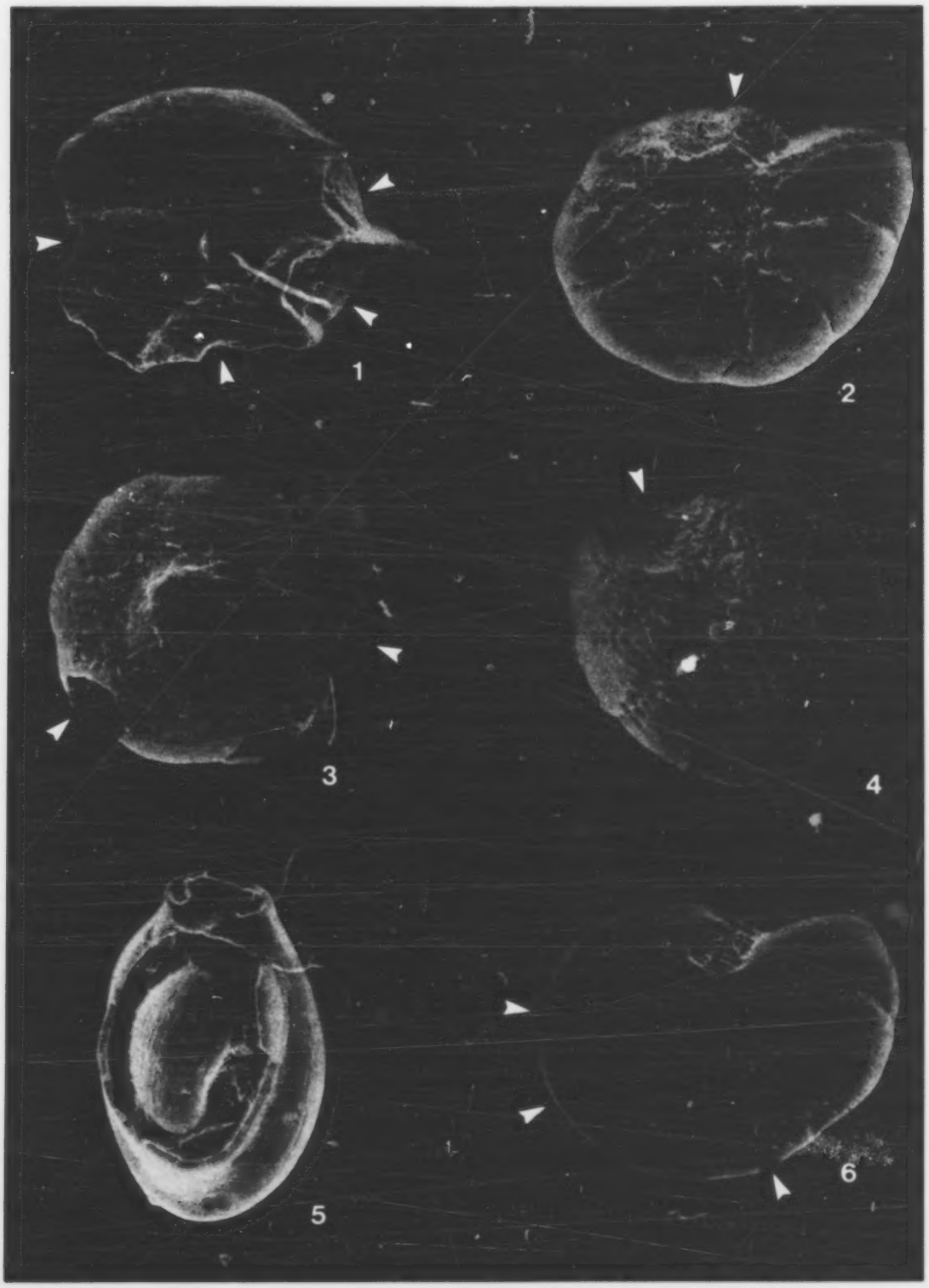
Small Species

Eggerella advena (Cushman), a relatively small species (see Table 2), is found at more than 50% of the stations studied (Fig. 10). It tends, however, to be absent or reduced in numbers where sandy bottoms exist. Its agglutinated test, averaging 0.28 mm in length in the study area, rarely appears to exhibit any degree of abrasional damage, despite its occurrence in several deep-water, high-velocity tidal current localities.

Elphidium frigidum (Cushman), the other small common species in the study area, was observed in more than 60% of the samples examined (Fig. 11), sometimes in large numbers (Table 3). This species is a very fragile form which is easily damaged when handled under the microscope. It is found in nearshore marine to estuarine environments elsewhere in the Maritime provinces where sediments are poorly sorted (Schafer and Cole, 1978). Loose (1970) reported living specimens of this species as being common in plankton tows off Bodega Head, California. He speculated that the specimens which he found in the water column were originally living in the intertidal areas but were transported up to at least 0.5 km from shore by wave turbulence and tidal currents. Significantly, the transported specimens were smaller than the mean diameter for the species in that area, suggesting selective erosion and transport of the individuals encountered in the plankton tows.

When the relative distributions, average test sizes and comparative degrees of abrasional test damage seen on the common foraminiferal species in the study area are considered collectively, a qualitative distribution process model can be postulated. Given the powerful tidal currents prevalent in the basin (Amos and Joice, 1977), the evidence strongly supports the existence of tidally induced transport of at least empty foraminiferal tests, and quite possibly living specimens as was also reported by Loose (1970). This foraminiferal transport could be taking place in two separate modes:

1. Bed load transport of large robust-tested species such as *Ammonia beccarii*, *Quinqueloculina seminulum* and others, resulting in extensive test damage to many individuals of these species.
2. Suspension transport of small, relatively fragile forms such as *Elphidium frigidum* and *Eggerella advena*. This mode of transport would substan-


1
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tially reduce the net effect of abrasion on the tests of these species.

Taxa of intermediate size such as *E. excavatum* group and other hydraulically compatible forms could be alternatively subject to either mode of transport at different times.

Test Transport Effects

In the Bristol Channel and Severn estuary (U.K.), Murray and Hawkins (1976) reported that suspended fine sediments (including benthonic foraminiferal tests) were moved from the outer reaches of the Bristol Channel into the Severn estuary by a combination of wind-generated currents, wave turbulence and tides. In the differential two-way sediment transport model described by Culver (1980) for the same area, this up estuary movement of suspended fine sediments was found to be associated with the movement of sand-size material seaward along the south side of the Channel. This seaward movement of sediment was concluded to be tidally powered and to have occurred as a bed load transport process.

Amos and Alföldi (1979) have described a somewhat comparable process involving the transport of fine sediment suspended in the water column eastward into the basin from the Bay of Fundy. They note, however, that the presence of extensive, current-rippled sand bars at various sites in the basin indicates a concurrent bed load transport mechanism that is primarily tidal current-controlled. This is in contrast to the combined wind-, wave-, and tide-generated currents described by Murray and Hawkins (1976) for the Severn estuary.

Among the evidence for bed load transport of sediment in the intertidal areas of the basin is the abraded condition of the tests of several foraminiferal species observed in this study. In many instances individual specimens have been reduced to barely recognizable fragments, probably as a result of intense abrasion during transport as part of the bed load, a process that would be repeated during successive tidal cycles. This transport process is also indicated by test walls that are perforated in many places. The perforation form of abrasion appears to have been confined to the relatively large and robust tests. Observations reported in the literature suggest that the destruction of tests by abrasion on sandy beaches also resulted in the loss of the comparatively small species and in damage to the skeletons of the larger species (Murray, 1973).

Culver (1980) indicated that in the Severn estuary, the suspended fine sediment which included benthonic foraminifera tests was concentrated in stable estuarine inlets by wind-generated currents. A somewhat analogous concentration process appears to be active in the central and lower reaches of the Avon estuary where a zone of high foraminiferal test concentration occurs in the bottom sediment (Fig. 12). However, in this instance, the zone appears to be indicative of interacting ebb-tidal currents since winds are apparently quite variable and local in character throughout the basin, and would not be sufficiently powerful to modify the ebb-tide current pattern (Amos, personal communication). Postma (1967) noted that all turbid estuaries exhibit concentrations of finer sediments (less than 100 microns) in nearshore areas as a result of settling lag (i.e., the delayed deposition of relatively fine material at the turn of the tide). Presumably this fine material could contain some smaller foraminifera; however, it appears unlikely that this process alone could be responsible for the high concentrations of larger foraminifera found in the central and lower reaches of the Avon estuary (Table 2), even if allowances are made for their lower envelope densities.

In contrast, the sparse number of tests in the central part of the basin is in agreement with the occurrence of conditions that promote the development of the coarse (gravelly-sand) sediment in this area. These sediments are indicative of strong bottom currents.

←

PLATE 1

1 *Cibicides lobatulus* (Walker and Jacob). Dorsal view of extremely abraded specimen. Arrows indicate sites of chamber abrasion and removal in outer whorl. ×250. From sample no. 114.

2 *Elphidium excavatum* (Terquem) group. Very abraded specimen. Arrow indicates site of chambers removed by abrasion from outer whorl. ×190. From sample no. 114.

3 *Ammonia beccarii* (Linné). Dorsal view. Arrows indicate chamber walls completely pierced in two places. ×90. From sample no. 29.

4 *Ammonia beccarii* (Linné). Ventral view. Arrow indicates site of missing final chamber. ×90. From sample no. 29.

5 *Pyrgo williamsoni* (Silvestri). Very abraded specimen exhibiting removal of one entire chamber and infilling of interior by sediment. ×130. From sample no. 29.

6 *Elphidium excavatum* (Terquem) group. Arrows indicate some sites of solution pitting. ×210. From sample no. 29.

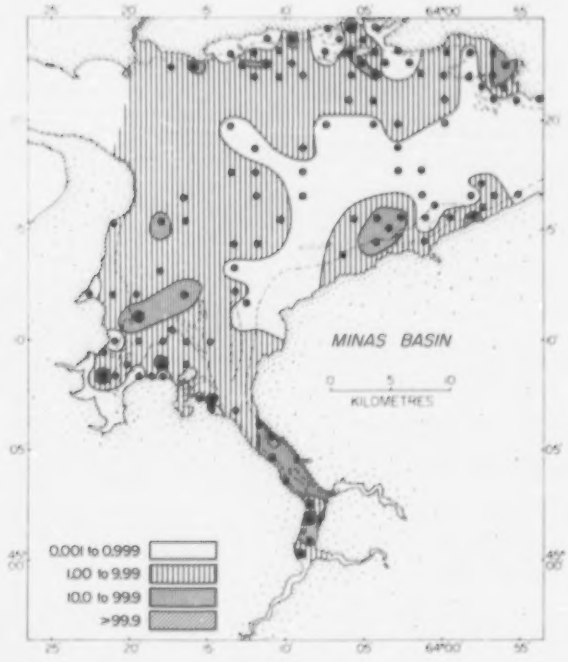

FIGURE 12

Distribution of the number of specimens per gram of dry sediment for the total population.

Underwater television observations in bottom areas near the mouth of the basin show a cobble substrate with attached algal forms that is apparently related to high bottom current speeds (Amos and others, 1976). According to Amos (personal communication), tidal currents tend to be strongest during the flood in the subtidal parts of the basin and promote a net transport of sediments eastward toward the head of the basin. This mode of transport is somewhat comparable to the bed load transport observed in the Bristol Channel (Culver, 1980), except that in the Bristol Channel the sediments are moved seaward as part of the bed load.

A second mechanism of test transport may occur in the basin for those specimens that are lying on the surface of intertidal flat sediments. These individuals could be dried out during low tide and therefore reduced in weight so that they might be easily picked up by the incoming tide or by the wind (e.g., Murray, 1973). According to Sheehan and Banner (1972), moist mud samples collected from below a dried out mud surface have yielded living *Elphidium incertum* (Williamson), suggesting that despite the frequency of this transport mechanism, a fraction of the living population can be retained in the source sediment to generate new populations. In the Jade area of Germany, Richter (1965) describes a situation in which the surface sediment layer, with its contained foraminiferal assemblage, is frozen into the bottom of ice rafts that form in intertidal areas. These ice rafts then move towards shore on the rising tide. The same ice-rafting process occurs extensively in the Minas Basin during the winter and spring seasons (Amos, personal communication) and could be an important ancillary method of test dispersion in this area. All of these transport processes appear to be significant in the study area because of its large tidal range and extensive tidal flats.

SUMMARY AND CONCLUSIONS

The foraminiferal species distributions described in this report may have potential for use as indicators of the transport direction of bottom sediments and for determining the source of suspended sediments. Data collected to date also provide a baseline that may have application in assessing changes in the benthic environment that may come about as a result of the construction of barriers that have been proposed for this area as part of a large scale tidal power project. The potential of these foraminiferal species for use as environmental indicators could be augmented in follow-up studies through consideration of both living and total species population distributions.

The samples evaluated for this study indicate that:

1. Three foraminiferal associations (thanatocoenoses) can be distinguished intuitively in the Minas Basin. Their composition appears to be, in part, related to mixing of indigenous and allochthonous elements from adjacent environments, and/or to intra-environmental test transport processes in the sense of Culver and Banner (1978). *Miliammina fusca* is the dominant species in an intertidal association; *Elphidium margaritaceum* and *Quinqueloculina seminulum* are prominent members of nearshore restricted and nearshore ubiquitous associations, respectively.
2. Depending on the species, the mode of test transport may be primarily in suspension and/or as part of the bed load. *Elphidium frigidum* appears to be carried above the bottom and probably bypasses the west central part of the basin where tidal currents are relatively strong throughout the entire water column. Other species show extensive pitting and test abrasion, suggesting transport as part of the bed load.
3. The anomalously shallow water occurrence of

Pyrgo williamsoni in the basin and the occurrence of planktonic foraminifera tests in the Avon estuary suggest a net transport of tests from the Bay of Fundy into the Minas Basin by tidal currents.

4. The distribution pattern of *Ammonia beccarii* and *Elphidium margaritaceum* indicates that summer bottom waters in the shallow nearshore and intertidal areas of the basin are relatively warm compared to most Atlantic coast nearshore environments that have been investigated at these latitudes. This observation seems to support the view that, for short periods at least, there is some temperature stratification of the basin water column (Amos, 1979) and that intertidal areas warm sufficiently during the summer season to allow the reproduction of these two species.

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